TECHNOLOGY ASSESSMENT OF SPACE STATIONS

Vary Taylor Coates
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PROGRAM OF POLICY STUDIES IN SCIENCE AND TECHNOLOGY

The George Washington University
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INTRODUCTION

This paper attempts to survey the social impacts, both beneficial and detrimental, which can be expected from a system of manned spacecraft operating over relatively long periods of time in Earth orbit, hereafter called space stations. It is, therefore, an exercise in technology assessment. It is futuristic in nature; that is, it anticipates technological applications which are still in the planning stage, and many of the conclusions are highly speculative and for this reason controversial.

As a general rule, technologies develop from an early stage in which human labor is extensively or exclusively used, to a later, more sophisticated stage in which mechanization and automation is substituted for the less efficient uses of human labor. Human labor is cheaper and more expendable at the early stages; but after capital, technical knowledge, and marketability have accumulated, complex automation--although expensive to develop and install--may be justified by its added efficiency and precision, and by the relatively smaller cost of upkeep and depreciation. In space technology, however, it is the use of man as part of the system which must be justified. The space systems which were first operational and which are currently most productive in application are those which are fully automated and instrumented. Because of the difficulty of maintaining human life in the environment of space, and the added weight and reliability which a man and his life support systems entail, there is a very real question as to whether the use of manned flight can be justified

on a cost effective basis, and if so, for what purposes. Does a human crew add in flexibility, observational acuity, initiative, and innovation to a sufficient degree to justify its presence?

The following questions will be examined:

- What beneficial or detrimental impacts might be expected to flow from a continued or expanded space program, in terms of science, practical applications, national security and world peace, industry, medicine, and social programs?

- To what extent do these beneficial or detrimental impacts depend on a program of manned space flight, as contrasted with fully automated systems?

- Are any of the beneficial or detrimental impacts which can be foreseen unique to manned Earth-orbital space stations as distinct from other kinds of space systems?

- Is the likelihood and extent of these beneficial or detrimental impacts judged to be sufficient to justify continuation of space research in the direction of such space stations for the near future?

The ideal in answering these questions would be a cost-benefit analysis. This is a tool which has been developed to facilitate the allocation of public resources in the most efficient way for the meeting of public needs. It involves the selection of objectives, identification of alternate strategies for reaching the objectives, quantification of costs and benefits and probability of success for each of the alternate strategies.

It is difficult to do a convincing cost-benefit analysis of space stations within the present state of the art. At present we are able to

quantify only in a very rudimentary way some of the factors which are to be maximized, such as prestige, security, peace, and scientific knowledge. Even "practical applications" of space activity are highly speculative in its present early stage of development. Most aspects of space technology are still in an R&D stage; this is the most difficult problem of all for cost-benefit analysis, since results are by definition unknown and unpredictable.

As a second best course, impacts will be surveyed in a general and qualitative way, with quantified estimates noted wherever they have been attempted, and with full recognition that both quantified and qualified statements remain in every case speculative and judgmental.

For the purposes of this paper, the term "space station" will be used to mean a spacecraft providing living space and work space for a crew of two or more, and designed to be operated in Earth orbit for an extended period of time. Such stations are variously spoken of, within the civilian and military space agencies, as skylabs, orbiting workshops, laboratories, platforms, etc. There have not yet been any "space stations" within this meaning of the term. The concept has been on NASA's list of potential programs since 1960, and has been a strong possibility since the beginning of both the United States' and the Soviet Union's space programs. In the case of the U.S., it was pushed aside by the formal commitment to achieve a lunar landing within a decade.

In the context of this paper, the term "space shuttle" (some writers use the term "ferry") signifies a recoverable and reusable spacecraft for transportation of crew and supplies to and from space stations or perhaps lunar

stations. Economic analysis shows that the greatest potential for reducing costs of space operations is in reuse of the craft.[1] It is generally agreed that any practical applications of manned space flight other than planetary exploration will depend on drastic reduction of the cost of space transportation to $100 per pound or lower.

A NASA Advisory Committee says that "achievement of a manned low-cost transportation system is the keystone to the future development and large scale practical application of the space program."[2] As this paper is completed, in early 1971, space station development has been pushed back until the 1980's, emphasis being placed on prior development of a re-usable space shuttle capable of short duration orbital missions (7 days), delivery of space probes, and other miscellaneous near-Earth missions. This shuttle will itself therefore include many of the characteristics of an early space station. However, an experimental space station, now called "Skylab", will be flown in two to three years, carrying various scientific experiments; 56 of these have been selected already. NASA budgeted about $30 million this year, and will spend about the same amount in 1972, for space station planning. A concerted effort is being made, through a series of national and regional conferences, and through establishment of scientific advisory

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[1] H. L. Hislop, "The Economic Considerations of Space Operations," Practical Space Applications; Vol. 21: Advances in the Astronomical Sciences (Washington, D. C.: American Astronomical Society, 1967).

[2] National Astronautics and Space Administration, Science and Technology Advisory Committee for Manned Space Flight 1975-1985, Proceedings of the Winter Study on Uses of Manned Space Flight, December 6-9, 1968, Vol. 1, p. 5.

panels, to involve a large segment of the scientific and industrial community in planning the utilization of space stations research and development. This paper is intended to provide one input into the continuing discussion, using the interdisciplinary techniques of technology assessment to raise the question of the overall impacts of this new technological application on social, political, environmental, and economic processes.

NASA has contended that manned space stations are a logical intermediate step toward the long-range goal of planetary exploration to advance scientific knowledge for benefit of mankind;* that the acceptance of a space station program is necessary to maintain the viability of a manned space flight program, to avoid the dissipation and wastage of hard-earned capability, and to maintain options in later space activity; and that space stations will provide valuable laboratories for scientific research and development.

The House Committee on Science and Astronautics said in 1969: "Once the space station is established, its use for research observations and operational activities can be determined on the basis of priorities and resources available at a given point in time."[3] This is a much more straightforward account of the way in which missions are planned than that usually given by NASA. Public presentation of goals and objectives tend to imply that scientific needs are a paramount reason for the development of new

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*By March 1971, NASA is downplaying this rationale somewhat and emphasizing its usefulness for short duration orbital missions.

[3]U. S. Congress, Senate, Committee on Aeronautical and Space Sciences, NASA Authorization for Fiscal Year 1970, H.R. 11271. Sen. Rept. 91-282, 91st Cong., 1st Sess., June 26, 1969, p. 18.

programs.[4]

Close observation suggests that instead programs are planned to serve the developmental and organizational goals and to fit into a logical plan of action designed to expand or maintain the scope of the space effort. Experiment packages are designed in consultation with non-NASA scientists to fit the capabilities of the mission, given constraints of weight, time, and resources, rather than the other way around. There have been widespread reports of dissatisfaction among the general scientific community with the amount of attention paid by the space agency to scientific priorities. This criticism began very early. It was inevitable as soon as President Kennedy enunciated the primary goal to be the lunar landing; if scientific investigation were the chief aspiration instead of placing men on the moon, modes of procedure would have been correspondingly different.[5]

The House Committee on Government Operations recognized some years ago that "There will be a great deal of scientific knowledge gained, but primarily (the Apollo program) is a great engineering, hardware-building, and training effort, not a scientific investigation.[6] Even prior to the adoption of the goal of a lunar landing, scientific objectives were

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[4]William B. Taylor, "Applications of Saturn-Apollo Systems," Practical Space Applications; Vol. 21: Advances in the Astronomical Sciences, (Washington, D. C. : American Astronomical Society, 1967), p. 127.

[5]Rosholt, An Administrative History of NASA, 1958-1963, prepared under the auspices of the NASA Historical Staff (Washington, D. C.: 1966). NASA SP-4101, p. 284.

[6]U. S. Congress, House, Government Operations in Space, 13th Report of the Committee on Government Operations, House Rept. No. 445, 89th Congress, 1sr Sess., June 4, 1965, p. 4.

secondary to military objectives and international prestige.[7]

It must be noted, however, that while the urging of scientists who were planning for the International Geophysical Year was instrumental in persuading President Eisenhower to announce, somewhat reluctantly, a national space effort, it was the preliminary planning and insistence of the military services which prepared the way for the program and carried it through the beginning stages, helped along by the public and Congressional indignation at the launching of Sputnik I and II.

On the one hand, space science either of the manned or unmanned variety, is costly in dollars and time. Experimental packages must be "frozen" early, often years in advance of flight. On the other hand, scientists themselves seem to show relative lack of flexibility and imagination in adapting methods and perceiving the potential of space technology for scientific experimentation. The same "hurdle of user acceptance,"[8] which often slows the development of technology applications, can also apply in planning scientific investigations. Scientists are not immune to what Hislop calls "cranial vapor-lock", or the tendency to maintain concepts that were successful in the past without adequate consideration of new methodologies. The impatience of scientists with what they view as over-attention to engineering tasks, may prevent them from anticipating future opportunities that might be opened by the development of space technology.

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[7]A subsequent paper by the present author will be concerned with political decision-making in regard to space stations.

[8]Phrase used by Harry J. Goett in "A Retroactive Look at the Application Satellite," Practical Space Applications; Vol. 21: Advances in the Astronomical Sciences (Washington, D. C. : Astronomical Society, 1967), p. 7.

Another aspect of the scientists-engineers tension over the space program is related to the question of whether the expenditures necessary to maintain Man in space are justified. Some point to the advantages of human dexterity, innovativeness, skill, imagination, and flexibility.[9] Others argue that either a "closed-loop", completely automated system, or an "open-loop" system controlled by man from Earth, is preferable for scientific purposes. Man in space is preoccupied with survival, introduces an unnecessary potential for error, and contaminates experiments and environment with organic materials. In judging the potential benefits to various scientific disciplines of space stations, such factors must be taken into account.

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[9] The arguments pro and con are summed up in: Siegfried J. Gerathewohl, "Man's Role in Space," International Science and Technology, Sept. 1965, and R.L.F. Boyd, "In Space: Instruments or Man?" International Science and Technology, May 1965.

I. THE ADVANCEMENT OF SCIENTIFIC KNOWLEDGE

Goals and Objectives

NASA lists as its primary goal "To explore and utilize space environment to advance human knowledge and to benefit mankind." This in turn is a paraphrase of the provision in the Space Act of 1958 which states that space activities "shall be conducted so as to contribute...to the expansion of human knowledge of phenomena in the atmosphere and space...." Space science, then, should be a basic purpose in all space activity.

The broad questions which space science must answer are:

- The nature of the dynamic processes which shape Man's environment
- The possibilty of extraterrestrial life
- The origin and evolution of terrestrial life
- The origin and evolution of the Earth, Sun, planets, and solar system
- The universality of physical laws

The expansion of scientific knowledge which began with the first efforts in space a decade ago has already shed some light on these questions. Even the few very simple experiments performed during the first lunar landing were directed toward answering specific questions concerning the force of gravity, the origin and internal structure of the Moon, the composition of the solar wind, the variations in the Earth's spin on its axis, and the drift of continents in relation to one another.

Astronomy

The advantages of space environment for astronomy are in the main twofold: to avoid "shimmer," or distortion from the scattering of light by the atmosphere; and to avoid the failure of the atmosphere to transmit high energy radiation. A large telescope placed in orbit transmits data with higher resolution than is possible from ground-based telescopes. (It should be noted immediately that this does not necessarily require an astronomer in space, since telescopes can be operated from Earth-based consoles.) With orbiting telescopes and spectrometers the entire spectrum of radiation can be utilized whereas the atmosphere will not transmit to Earth high-energy radiation such as long-wave radio, much of the infrared, the far ultraviolet, X-ray, and gamma ray portions of the spectrum.[10]

Many astronomers assert that manned astronomical facilities are neither necessary or desirable, because a human presence introduces error into the system and requires for support a huge allocation of resources which would be more productively spent on instrumentation.[11] Others insist that on-the-spot decisions and the desirability of recovering photographic plates make manned systems desirable.

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[10] Neville J. Woolf, "The Impact of Space Studies on Astronomy," Impact of Space Exploration on Society: V. 8, Science and Technology Series (American Astronautical Society: 1966).

[11] Based on interviews with astronomers and other scientists at the Space Science Board and elsewhere. This is not alleged to be a quotation from an individual informant. In the Space Science Board study (National Academy of Sciences-National Research Council, Planetary Exploration, 1968-1975, Report of a Study by the Space Science Board, (June 1968), p. 16) cited, however, the Board said, "...we favor reallocation to the unmanned exploration of the planets those resources directed to efforts preparatory to a manned planetary program."

There are three alternate modes of astronomical space research: automated facilities (perhaps with highly redundant systems); observatories as an integral part of a manned system; and modular observatories serviceable by rendezvous with a space shuttle or with a separate manned facility, that is, a module detachable from a station. With either of the two latter modes there are potential "pointing" and contamination problems, as with any other manned laboratory. A manned telescope will weigh many tons, and will have to be pointed within a total angle accuracy of one arc second or less and hold the pointing within a total angle of less than 0.01 arc seconds. It must be possible to change the pointing from one source to another quickly. The supporting structure must hold components many tens of feet apart in position relative to one another within one thousandth of an inch or better under extremes of temperature.[12] Some of these constraints also would operate on unmanned structures, but in general to a lesser degree because they are smaller and more compact. A report by a NASA Advisory Committee concluded:

> *Man as a scientist in space is apparently not necessary to astronomy*. However when we are dealing with large, complex, and hopefully long-lived telescopes, we are faced with an economic decision as to whether man should maintain and update the instruments in space. Instruments such as the long focus solar telescope appear more feasible if manned deployment and adjustment are possible. (italics mine)[13]

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[12] NASA Office of Space Science and Applications, *Objectives and Goals in Space Science and Applications*, pp. 4-11 and 4-12.

[13] NASA Science and Technology Advisory Committee for Manned Space Flight, *Proceedings of the Winter Study on Uses of Manned Space Flight 1975-1985*, (Dec. 6-9, 1968), Vol. I, p. 22, SP 196.

The President's Science Advisory Committee (1968) said that one of the primary goals of our space efforts should be development of an orbiting astronomical laboratory including "extending useful life through intermittent maintenance and modernization by servicing in orbit."[14] In other words, the decision may ultimately depend on the cost of transporting a crew into space for servicing.

An automated satellite could be abandoned when it failed, and an identical or a more advanced system be flown to replace it at the present time more cheaply than a crew could be sent into orbit or on a repair mission. Or, automated astronomical satellites can be provided with redundant instrument systems less expensively than with human crews. Development of a space shuttle which drastically reduced the cost of transportation into space for a repair crew might be more feasible than orbiting a crew along with the telescope. There are also difficulties in putting a manned craft into some of the orbits which are desirable for astronomical purposes because of the necessity for over-water launches.

Physics

Space physics has already produced a great amount of information concerning measurements in space, high energy radiation, the Van Allen Belts, and the composition of the near-Earth environment.

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[14] NASA Office of Space Science and Applications, Objectives and Goals in Space Science and Applications, 1968, p. 3-3. SP 162.

Future tasks for space physics include investigations of the regions of space where most of the absorption of solar ultraviolet radiation occurs, in the near Earth environment, and where an abrupt decrease in charged particle concentration has been observed (the plasmapause), and the upper portion of the ionosphere where paths of ionized atoms are convected by the magnetic field. Other needs are for study of the magnetosphere, of interplanetary space, and the solar wind. The amount of carbon dioxide in Earth's atmosphere has increased by 8% during the last half century; if this rise continues it may bring about a gradual rise in the temperature which may be accompanied by a decrease in the amount of oxygen in the air. Survival may eventually depend on understanding these and other changes in the atmosphere.[15]

Some experiments can be performed in space which are either difficult or impossible in a physics laboratory on Earth. They include tests of the predictions of the general theory of relativity with a hydrogen maser clock, investigation of the behavior of liquids, solids, and gases under gravity-free conditions and without containers; investigations of very high energy particles, and the study of plasmas on a large scale. For the study of high energy particles instruments with large apertures are necessary, and this is a possible need for a manned laboratory.[16]

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[15] General Electric Company, Space Division, Apollo Systems Department, Benefits from Space, (March, 1969). Study compiled from Stanford Research Institute, The Benefits of the National Space Program and their Application and Understanding by the American Public, Vol. II, prepared for G.E.

[16] NASA Science and Technology Advisory Committee for Manned Space Flight, op.cit., pp. 22-26.

The necessity for man as a part of the instrument system for physics experiments remains an open question. The NASA Advisory Committee maintained that

> While unmanned satellites of moderate size can study cosmic rays, they are severely limited in weight, versatility, and reliability. The increased payload possible on a manned station together with man to rearrange and service the equipment provide far greater capabilities.... We believe that...without man, useful physics programs in some areas can be continued but to a more limited extent.[17]

Early space stations will include simple physics experiments such as a study of the spacecraft environment and the behavior of liquids, solids, and gasses in gravity-free conditions.

As to the possiblity of detrimental effects, the committee on Potential Contamination and Interference from Space Experiments reviewed experiments in the fields of electromagnetic radiation, energetic elementary particles, ion clouds, and contamination, and concluded that none of them could be expected to produce harmful effects.[18]

Bioscience

Space biology, in its current state, concentrates on five basic questions:

-- The possiblity of extraterrestrial life

-- The prerequisites for life and hence the development of theories and models relative to the origin and evolution of life

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17 Ibid., p. 35.

18 Op.cit.

-- The effect of environment, including day-night cycles, on life

-- The effect of weightlessness and radiation on man and other organisms

-- Contamination of space by man and back-contamination of the Earth.

The Biosatellite program used automated spacecraft with a parachute descent recovered in mid-air by airplanes to study the effects of weightlessness and radiation on metabolism, growth, and reproduction of relatively simple plant and animal tissues.[19] In 1969, the first of a pair of planned 30-day flights was orbited using an elaborately instrumented monkey which unexpectedly sickened in orbit and died soon after recovery. Biomedical investigators warned that the monkey apparently died of the effects of weightlessness, and that NASA not proceed with plans for either extended manned flights or space stations until more biomedical data was in hand.[20] Further biomedical flights were canceled or postponed for economy reasons.

Bioscience is the discipline which is most likely to profit from the presence of man in the system. This is because living organisms are complex and relatively unpredictable and it is difficult to automate an entire sequence of biological experiments. Those which require a series of steps profit by the presence of a biologist to observe unexpected reactions and to vary conditions accordingly.

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19 NASA Office of Space Science and Applications, Objectives and Goals in Space Science and Applications, 1968, p. 4-25

20 Washington Science Trends, Vol. XXIII. No. 3, Oct. 27, 1969. Washington Post, Nov. 14, 1969.

On the other hand bioscience has distinct disadvantages from the point of view of the experimenter. Space experiment may cost thousands of dollars of limited research funds and may take three to five years preplanning, and is relatively inflexable to change during that period.[21]

One biological task proposed for space stations is to search for extra-terrestrial life by remote-sensor seeking of emission or absorption patterns characteristic of life-associated molecules, and the collectior and analysis of micrometeoroids and interplanetary dust for organic macromolecular content. But these tasks can be performed by automated devices; and in fact contamination by human organic wastes would be a constant danger to such experiments in manned craft.

NASA's Advisory Committee held out the hope that

> The availability of skilled men who can function in the space station allows for designs radically different from those required for unmanned space experiments. It can result in lower experimental costs, broader flexibility, increased reliability, and longer useful lifetimes for the experiments.[22]

It is not very certain that this is true for science in general but it may prove true of biological laboratories where the increased flexibility, selectivity, and even subjectivity of the human experimenter may pay off in choice of adaptive procedures and longer survival for valuable subject animals. Man himself, of course, may be the most informative subject of the experiments.

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21 NAS-NRC-NAE News Report, "Group to Re-evaluate Biosatellite Program as a Part of Review of Space Biology Effort," June-July 1969.

22 NASA Science and Technology Advisory Committee for Manned Space Flight, op.cit., p. 28.

Experimental packages that have been suggested for inclusion in early space stations include instrumented monkeys for study of behavior, electrophysiology, metabolism, hemodynamics, cardiovascular adaptation during weightlessness, and related studies of micro-organisms, tissues, small vertebrates, plant species, and invertebrates.

It is also worth noting that the biosciences have benefited indirectly from the space program through the development of instrumentation and techniques of general value to biological scientists. Examples are an underwater "pinger" for studies of ocean currents and fish movements,[23] a cross-correlated spectral analysis computer program for studies of brain activity, biosensors for monitoring muscle activity, breathing, and blood flow, and a micrometeorite transducer which can measure heartbeats in animal embryos.[24]

Geodesy

The objectives of geodesy are to determine the shape and size of the Earth and the dimensions of its gravitational field. The National Geodetic Satellite Program beginning in 1962 learned more in the first few months of satellite geodesy than was learned in the previous two centuries. A world-wide system of reference points has been established. Through further experiments like the laser reflector placed on the Moon, further refinements will be made in measuring the continental drift and

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23 NASA Office of Technology Utilization, Summary Descriptive Information on a Random Selection of Transfer Examples, (March 1969, mme.).

24 U.S. Congress, House, Rept. on NASA Authorization FY 1969, *op.cit.*, Appendix A.

vertical uplift of land masses, wandering of terrestrial poles, measurements of land movement along fault zones, and long term changes in the Earth's gravitational field. Prediction of earth-quakes and tsunami will be improved through this knowledge. There is however no indication so far that man is desirable or necessary in these systems.

Planetary Exploration

The Space Science Board said in 1965, "We recommend planetary exploration as the most rewarding scientific objective for the 1970-85 period."[25] The earth is one of the nine planets circling the sun, but astrophysics is in many ways further developed than planetary science; stars radiate light, the analysis of which tells a great deal about their composition, and they can be observed in many stages of formation and development. We lack comparative data about the differentation of the interiors of planets, the internal activity and the physical, chemical, and mineralogical composition of planets other than Earth, and the properties and behavior of other planets' atmospheres.

Unmanned satellites and space probes have begun to answer these questions, to provide information on the atmosphere and magnetic field of Venus, and close-up photographs of Mars, supplemented at closer range by computer-enhanced television shots.

In two studies, one of planetary exploration and the other of the outer solar system, the NAS Space Science Board has urged that highest

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[25] National Academy of Sciences, Space Research: Directions for the Future, Summary of Conclusions of the Space Science Board Summer Study at Woods Hole (June, July, 1965).

priority be given to planetary exploration as the next step in the space program, including reallocation to this program of fully automated probes all those resources which might be spent on a manned planetary program.[26] There is a particular urgency to this program because an unusual positioning of the planets will occur in the late 1970's which would allow probes to make "the grand tour" visiting several outer planets with a minimum expenditure of fuel by ricocheting like a billiard ball from one gravitational field to another. This favorable set of circumstances will not occur again for nearly two centuries. A vigorous program of exploration of outer space could be developed for a fraction of the cost of a manned space program, even one limited to the Moon and near planets. Accordingly, plans for two three-planet "grand tours," one a fly-by of Jupiter, Saturn, and Pluto, and the other of Jupiter, Uranus, and Neptune, are being developed.[27]

Other advisory groups have placed a higher value on manned exploration. The President's Science Advisory Committee in 1967 urged "a program of technology development and of qualification of man for long-duration space flight in anticipation of manned planetary exploration." The usual arguments advanced that it is "man's nature" to explore, to do what he is potentially capable of doing to assert himself in the face

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[26] NAS-NRC, Planetary Exploration, 1968-1975, The Outer Solar System: A Program for Exploration, Report of the Space Science Board, 1969.

[27] Optical Spectra, May-June, 1969, p.22.

of hostile nature. More specifically, some urge that man alone can be trusted to observe and report on the unanticipated and unprogrammed, and others that the most important objective is "to keep our options open." The Space Task group, a Presidential advisory group on the cabinet level, formally made this recommendation in September, 1969: "as a focus for the development of new capability, we recommend the United States accept the long range option or goal of manned planetary exploration with a manned Mars mission before the end of this century as the first target."[28]

There is greater agreement that _if_ manned planetary exploration is to occur, the first and indispensable step in this direction must be space stations "to demonstrate capability for men to operate effectively in space for extended periods," and to perfect rendezvous, resupply, and orbital assembly techniques.[29] The space station would be a training and logistics support station for planetary trips whether accomplished by launch from Earth, from Earth-orbit, from a Moon station, or from lunar orbit. A low orbit space station appears to be the cheapest and safest way to learn the techniques necessary for longer duration survival in space especially if a space shuttle is developed.

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28 Space Task Group Report to the President, _The Post-Apollo Space Program: Directions for the Future_, September 1969, p. iii. See also "Man Moves into the Universe," _Bulletin of the Atomic Scientists_, Vol. XXV, No. 7, September 1969, p. 6.

29 William B. Taylor, "Applications of Saturn-Apollo Systems," _Practical Space Applications_; Vol. 21: _Advances in the Astronomical Sciences_ (Washington, D.C.: American Astronomical Society, 1967), p. 127.

A flight to Mars would take about two years. Methods would have to be worked out to ensure physical and mental survival of the crew, and environmental subsystems, life-support systems, on-board power systems, and the capability to launch such payloads, must be worked out.

A Saturn rocket takes about 3 and 1/2 years for fabrication. At the height of the Apollo operation Saturns were built at the rate of six a year. Production has now stopped. Three a year is about as low as production can be cut since two a year cost very nearly as much as three.[30] With three Saturns it would be feasible to use one or two for lunar exploration and the rest for a space station program. This appears to be a minimum program which would enable NASA to maintain a viable manned space program in terms of holding together a minimum team of designers, planners, engineers, and astronauts.[31] Dr. Glen Wilson, on the Staff of the Senate Committee on Aeronautics and Space Science, says

> Our ten year effort has been spent on engineering to make it possible to get where we are. Now we are just beginning to use it for something. We may later find that on balance it is not worthwhile to have man on the Moon or in space, but the only way to find out, is to try it.

Even those scientists who are most sceptical of manned space flight, tend to agree that it is necessary to maintain a minimum program in order to keep open the future options. This might imply an absolute

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[30]Based on discussions with Dr. Glenn Wilson, Staff of the Senate Committee on Aeronautics and Space Sciences, August 4, 1969.

[31]This point and the quotation below are from notes made of interviews with Dr. Wilson. While the quote may not be verbatim (I believe it is) Dr. Wilson subscribes to these views. The quotation in the second paragraph is also taken from notes of an interview, but in this case the speaker wishes to remain anonymous. The quote is however typical of several persons with whom this question was discussed.

bottom expenditure of between \$1.5 billion and \$2 billion to pay the overhead and maintain a staff. One scientist put it this way:

> There is really only one cogent argument for an orbiting Workshop...namely that at some future date it could turn out that it would be useful or necessary to send men into space and conceivably even to the planets. At the moment I don't know what this reason would be. Any task which can be done by man in space now can be done better by automation and scientists who don't work for the government are in general consensus on this.

II. PRACTICAL WORLD-WIDE APPLICATIONS

The basic objectives of a space station program, as far as world-wide applications is concerned, are to determine the proper relationship between manned and unmanned missions in terms of Earth resources, oceanography, meteorology, communications, navigation, and geodesy.[32]

The Stanford Research Institute in 1965 performed a priority analysis in order to advise the Advanced Manned Missions Program Office concerning experiments to be placed on a space station. The method consisted of using a panel of experts who were asked to estimate the economic value of productivity in a given area of the economy; a fixed percentage of this value was then taken to be a reasonable approximation of the improvement which might be realized in the form of savings from the application of space-derived information. This was recognized as a "crude first step only."[33] Shortly thereafter, the IBM Corporation undertook a study for similar purposes. The principle activity consisted of relating "objectives" to specific experiments and proposing an experiment program.[34] In the course of this study the team estimated

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[32] U.S. Congress, House, Committee on Science and Astronautics, Authorizing Appropriations to NASA FY 1969, to accom. H.R. 15856, House Rept. No. 1181, 90th Cong., 2nd Sess., p. 211.

[33] Stanford Research Institute Project M-5465, Sept. 1965, Priority Analysis of Manned Orbital Research Applications.

[34] IBM Corporation, Federal Systems Division, NASA Contract NASw-1215 (Feb. 1966), Orbiting Research Laboratory (ORL) Experimental Program.

annual benefits from applications in given areas. Table I below shows the estimates used in these two studies.[35]

TABLE I.

Application Area	Estimated Annual Benefits (in Millions of Dollars)			
	IBM		SRI	
	United States	World	United States	World
Agriculture/Forestry	0.9	11.0	0.015	0.030
Geology/Hydrology	2.7	6.6	0.005	0.010
Ocean/Marine Science	3.8	7.8	0.060	0.660
Geography	0.1	0.8	-----	-----
Atmospheric Science	30.0*	84.0	-----	-----**

* NAS-NRC estimated $2 billion a year for effect of long-range weather forecasting improvements.
** Indian Monsoon Prediction Case Study indicated of the order of $250 million yearly.

The Planning Research Corporation performed a benefit study of space station applications which was directed at estimating "the economic and supraeconomic benefits that could be realized by Governments or private industry when employing operational satellite-assisted information.[36] No attempt was made to decide whether the postulated satellite system should be manned or automated. The concept of a manned station was used only to provide an upper boundary for flight system performance and cost.

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[35] R.S. Summers, S.M. Smolensky, and A.H. Muir, Forecasting the Economic Impact of Future Space Station Operations, AIAA Paper No. 67 962, 4th Annual Meeting and Technical Display, Oct. 23-27, 1967.

[36] Planning Research Corporation, op.cit.

TABLE II

RANKING OF CANDIDATE AREAS FROM PLANNING RESEARCH CORPORATION BENEFIT STUDY

Candidates (1)	Est. Net Benefits Annually (in Millions)
Agriculture -- stress	$ 27,000
Health -- diseases of man	16,313
Agriculture -- inventory and yield	11,340
Oceanography -- fishing	1,560
Health -- diseases of animals	1,350
Natural disasters	645
Hydrology	373
Health -- solid wastes	189
Resource management -- soil survey	115
Geography -- mapping	114
Govt. Operations -- tax assessment	87
Search and rescue	57
Geophysics -- location of fuels and minerals	42
Health -- water pollution	19
Forestry	9
Oceanography -- monitoring icebergs	(2)
Georphysics -- erosion and silting	(2)
Agriculture -- location of new land	(2)
TOTAL	$ 59,230

(1) These candidate areas are much broader than the case studies: for example, "wheat rust" was a case study but is here included as a small part of "agricultural stress."
(2) Benefits est. less than $0.5 million.

The National Academy of Sciences was also asked by NASA to carry out an evaluation of Earth-oriented satellites and the report on this summer study was published in 1969.[37] They concluded that the practical applications of satellite technology were larger than had been expected earlier and recommended that NASA give very high priority to Earth-oriented satellite programs in the 1970's. They also said that these benefits did not justify the use of manned systems in themselves.

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[37] National Academy of Sciences, Useful Applications of Earth-Oriented Satellites, Summer Study on Space Applications, (Washington, D.C., 1969).

Earth-Resources and Oceanography

The Earth Resources satellites program may offer greater promise than any other space activity for "the benefit of all mankind." This was the conclusion of a United Nations Conference on Exploration and Peaceful Uses of Outer Space.[38] The object of the program is to improve the utilization and development of natural resources in five broad areas:

(1) Agriculture and forestry resources

(2) Geology and mineral resources

(3) Geography and cartography

(4) Hydrology and water resources

(5) Oceanography

This effort began before the space program with the use of aircraft and balloons to carry photographic and infrared devices. The current program includes both continuation of the aircraft flight program to further sensing techniques and instruments, and Earth Resources Technology satellites.[39]

There is some question of the additional utility of a manned Earth resources program utilizing space stations. Transmitting information from observational automated satellites is one difficulty. A given site on Earth, for example, can receive from a satellite orbiting 300 miles out for only 10 minutes each pass if the pass is made directly over

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[38] United Nations Conference on the Exploration and Peaceful Uses of Outer Space, "Space Science and Technology: Benefits to Developing Countries," Vienna, August, 1968. U.N. Pub. Sales No. E.68. I. 11.

[39] T.R.W. Space Log, Spring, 1969, Vol. 9, No. 1, pp. 16-17.

the ground station. The great value of a human operator would be to study the data as collected and transmit only selected portions of it, or to evaluate it and comment on it directly.

As is the case in other fields, it appears that the marginal benefits to Earth resources programs alone cannot justify the development of space stations on a cost-benefit basis, but if such stations are developed they may be advantageously utilized for Earth resource purposes, in this case to reduce the information transmittal load and to introduce a selectivity and flexibility capability into the system. But the development of instrumentation has proceeded to such a point that, as in the case of military surveillance, it appears to many to have "leap-frogged" the manned flight program and to be able to accomplish the same tasks at much less cost.[40] The biggest need now appears to be better methods of full dissemination and utilization of the data collected.

Meteorology

Losses caused by weather in the United States alone are estimated at 1200 lives and $11 billion a year.[41] Quantitative weather data is presently obtained at ground level over less that 20 percent of the Earth's surface, with the other 80 percent inaccessible except for a

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[40] U.S. Congress, House, Report on Authorizing Appropriations to NASA FY 1969, p. 157.

[41] Robert L. Marquardt (Vice-Pres., Economic Development Operations, Thiokol Chemical Corporation), "Areospace R&D and Social Programs," a speech to Aviation/Space Writers Association, Dayton, Ohio, May 15, 1969.

relatively small number of scattered observation stations.[42] Very early rocket photography in the late 1940's and early 1950's produced the first usable cloud cover photographs, but there was great skepticism among operating meteorologists as to the utility of global cloud cover photographs for weather prediction.[43] Existing methods were based on an entirely different type of data -- pressure and temperature distribution -- and theoretical models were based on those two types of data. "If the meteorologist had his preference then (and possibly now) he would have chosen data such as might be obtained from vertical soundings of pressure, temperature, and wind velocity, rather than cloud cover pictures...."[44] However, early studies, most of them by the Department of Defense for military purposes, pointed irrefutably to the feasibility of weather forecasting from cloud cover photography. We now have an operational system for satellite meteorology although forecasting needs a great deal of further development.

A National Academy of Sciences study estimated that a large part of the cost of the entire space program, could be covered by savings of farmers, fuel producers, public utilities, and builders, from an entirely adequate weather forecasting system, collecting and analyzing data, forecasting on an international basis, and making mathematical models of the world weather system.[45]

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[42]United Nations, op.cit., p. 10.

[43]Harry J. Goett, op.cit., p. 4.

[44]*Ibid.*

[45]National Academy of Sciences, Useful Applications of Earth-Oriented Satellites.

Several programs now in the planning and development stage would exploit the ability of satellites to provide inexpensive and efficient data collection and relay, by using merchant ships, buoys, or horizontal sounding balloons with automatic sensors to relay data through satellites. One problem is the amount of raw data which must be collected and transmitted in a brief time span. It is largely for this reason that some meteorologists would like to see development of manned meteorological facilities in space. For example, Sidney Sternberg, Vice-President of Optical Systems, argues that unmanned satellites can locate storms and track them by extrapolation but are not powerful enough or flexible enough to locate areas of new storm development and predict their build-up, or anticipate changes in a storm with respect to intensity or motion.[46]

But this seems to be contrary to the general consensus which indicates no real need for man in space as far as meteorology is concerned. The NASA Advisory Committee commented, "There is little support for man as a scientific operator; most functions can be pre-programmed or controlled from the ground."[47] There is of course the usual caveat that new and more ambitious instrument systems combined with lowered space transportation costs, might quickly change this assessment. However, it is more likely that development in meteorological instrumentation, as in other instrumentation, will move in the opposite direction of more computerization and miniaturization.

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[46]Sidney Sternberg, "Space Meteorology Past and Present," Practical Space Applications: Vol. 21, Advances in the Astronautical Sciences (Washington, D.C.: American Astronautical Society, 1967) p.36.

[47]NASA Science and Technology Advisory Committee on Manned Space Flight, op.cit.

The ultimate goal of meteorology may in fact be weather control and modification. A meaningful discussion of the needs of such a program in terms of manned and unmanned satellites must wait for further knowledge of the methods of weather determination.

Communications

Satellite communications relays were developed to serve urgent national and international needs for increased and reliable means of swift communication for purposes of national security, international cooperation, negotiation, warning systems, industry, finance, commerce, traffic control, rescue, and disaster relief.

Both the United States and the Soviet Union now have operational communications satellite systems. (U.S. Comsat is the U.S. Corporation which participates in Intelsats along with 67 other countries). Communications satellites are point-to-point systems designed for intercontinental transmission of all kinds of communication traffic. They are now the cheapest method of sending a moderate number of trunk messages over distances of 1500 miles or more. Point-to-point communications satellites have been less expensive than submarine cables since their inception and it is expected that eventually the break-even distance will be reduced to 100 miles or less.[48]

Broadcasting satellites are those which are capable of beaming a message directly to home receivers of conventional types and require more power than point-to-point systems. Distribution satellites are midway between the two types and transmit to ground relays for relay to home receivers. Broadcast satellites have great potential,

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[48] United Nations, op.cit., p. 5.

particularly in terms of education for developing nations, for example, in the birth control program, or for creating a national cohesiveness, or overcoming the problem of multiple languages, and in some countries of tribalism.[49] In addition to the benefits of improved communication, television satellites may eventually encourage the development of industry, including manufacture, distribution, and repair of television sets. But developing countries may lack the technology to make use of the advances in communications. As yet is is not clear to what extent communication can be a catalyst for economic development. It should be noted that this application has a great potential detrimental effect also, in terms of propaganda and thought control.

In satellite communications there is little indication of a role for man in space other than the possibility of a minimum function of deploying, servicing, and testing systems if a reliable shuttle can be developed.[50] It therefore seems that while space technology will make great contributions to world communication, space stations offer no unique benefits.

Navigation and Traffic Control

Satellites have application in terms of (1) relaying communications between ships and aircraft and between craft and ground sites, and (2) the use of space-borne sensors to provide data which can be used to determine

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[49] John W. Ludwig, Symposium Discussion, Practical Space Applications: Vol. 21 Advances in the Astronautical Sciences, pp. 449f.

[50] NASA Science and Technology Advisory Committee for Manned Space Flight, op.cit.

position and velocity, to monitor vehicle movements and to direct rescue operations. Simulations have indicated that selection of optimum shipping routes can save one percent fuel costs, one percent of revenue producing time, and one percent of the cost of the ship on insurance premiums.[51] This depends on having real-time information about weather, wind, drift, traffic, and hazards, which can be potentially provided by either space sensors or the relay of data gathered from multiple Earth stations. Accuracy of satellite-derived data might permit the reduction of present separation standards for air traffic while at the same time improving safety. Search and rescue operations could obviously be facilitated. In all these cases inquiry can be handled directly by computers. At present there is no indication that the systems would be improved by the presence of human operators. The National Academy of Sciences Summer Study of Earth-oriented satellites concluded:

> ...The manned program will provide significant opportunities to test sensors and to prove out techniques useful to applications...However the use of manned vehicles *per se* does not at present appear necessary or economically desirable for the operation of the various space-applications systems.... We believe that the systems...will be achieved more effectively and more economically with automated devices and vehicles.[52]

In the light of present technology there is no reason to reverse this conclusion. If however space stations are put in orbit for other reasons, there may well be considerable benefits from its application

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[51]NAS, *Useful Applications of Earth-Oriented Satellites*, Part II, Report of the Navigation and Traffic Control Panel, p. 71.

[52]National Academy of Sciences, *Useful Applications of Earth-Oriented Satellites*.

in a few specialized aspects of Earth resources and meteorology, where rapid selection, analysis, and transmittal of information may be important.

III. NATIONAL SECURITY AND INTERNATIONAL COOPERATION

Statements about military applications of satellites must always be made with the caution imposed by the Department of Defense preoccupation with secrecy. However, the material which appears in the public records, when examined in the light of the decision that was made to terminate the military space station program (MOL), allow one to reach at least some tentative conclusions concerning this subject.

Public interest in -- and official emphasis on -- manned space flight as a military system has declined in the last two or three years. In the late 1950's Congress viewed Sputnik I and II as a grave threat to our military superiority.[53]

The House Committee on Government Operations agreed in 1965 that "military needs have the highest priority" in the space program.[54] The industry publication Space/Aeronautics commented editorially, as late as January 1969, "Cancellation of MOL is out of the question on grounds of military security."[55] However, after termination of MOL in June 1969 there was remarkably little discussion of the security value of MOL, most of the criticism of the decision being made in terms of the resulting unemployment and waste of facilities. In part this was because the Department of Defense stressed that termination of MOL was preferable to cutting "numerous small programs" from its R&D budget,

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[53]Robert L. Rosholt, *op.cit.*, p. 13.

[54]U.S. Congress, House. *Government Operations in Space*.

[55]*Space/Aeronautics*, Vol. 51, No. 1, January 1969, "Manned Space Missions," p. 54.

and also stressed that the functions of MOL could be performed by automated systems.[56] Other reasons for the decline in emphasis on the military uses of space stations are

-- Accumulation of evidence that space flight will not have the fundamental effect on strategy that resulted from invention of aircraft and of atomic weapons

-- A period of relatively less tension between the U.S. and U.S.S.R., and a somewhat lower level of fighting in Vietnam

-- Growing sentiment for the reduction of government spending, which is now reaching the DoD as well as civilian agencies

-- Growing pressure to reallocate public spending from defense and space and toward urban and environmental problems

-- A policy of secrecy about military space activities that tends to remove them from public notice and reduces support as well as criticism

-- The successful lunar landing which finally ended the public's fear of failure in a presumed competition with the USSR

-- Official embarrassment at stressing military benefits in the face of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space.

The Treaty on the uses of outer space signed in 1967 under U.N. auspices does not forbid the use of space for surveillance. It would be difficult in practice to separate military surveillance from that which is carried out for practical applications. In any case no Power with the capacity to survey its competitors from space could refrain from exercising that ability for very long in times of international tension.

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[56] For example, Washington Post, June 11, 1969, A1.

Outlays for space research and exploration were a substantial part of the total DOD research budget in the 1960's.[57] Potential uses of space for military purposes, whether manned or unmanned flights, may be characterized as follows.

-- Defense against aggressive acts in space

-- Modification of general space applications for military purposes

-- Use of spacecraft for "chase and destroy" missions

-- Use of satellites as weapons systems

-- Surveillance and monitoring

For these purposes space flight has obvious advantages:[58] high altitude with line of sight to large areas, very high speed, long flight duration, and highly predictable flight paths. It also has certain strong contraints: expense, long preparation time, hostile environment, requirements of extreme precision, and relative difficulty of controlled return to a specified area.

As already noted, Congress reacted to Sputnik I with great anxiety about national security and a feeling of loss of national prestige at being beaten in a matter of technology. After the Gagarin flight in 1961, Professor N.A. Varvarov described Soviet objectives:

> This will be followed by the construction of flying laboratories with crews of several men, the launching of satellites to Mars and Venus, and the landing

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[57] U.S. Congress, Senate, National Space Goals for the Post-Apollo Period, Hearings before the Committee on Aeronautical and Space Sciences, 89th Cong., 1st Session, August, 1965, p. 303.

[58] Gen. B.A. Schriever, "Implications of Space Exploration for National Security," Impact of Space Exploration on Society: Vol. 8, Science and Technology Series (American Astronautical Society, 1966) pp. 25ff.

> of a rocket with scientific instruments on the Moon.[59]

Similarly, another Soviet academician said:

> In the not distant future...a big, permanent, artificial Earth sputnik will serve as a high scientific laboratory to conduct research into various types of cosmic radiation and study the effect of space flight on the human organism.[60]

In the U.S. such promises were interpeted as threats since, as Smith said, "Soviet military strategy acknowledges the need to study the use of space and space vehicles to reinforce the defense of the socialist countries."[61] Obviously therefore such forecasts affected DOD planning and the Air Force began to push its MOL program at about this time, although it was not accepted by Secretary McNamara until 1963, and then reluctantly.

Applications of space technology such as communication, navigation, meteorological, and geodetic satellites have obvious military utility. NASA's Syncom II (which relayed TV coverage of the 1964 Olympics from Japan to the U.S.) was transferred to DOD in 1965 to provide instant communication between headquarters and field forces in Vietnam.[62] DOD has its own navigation, geodetic, and surveillance programs using automated satellites.

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[59] George Washington University, Program of Policy Studies in Science and Technology, Major Factors in Aerospace Planning and Decision-Making, by Robert G. Smith (Washington, D.C.: 10 May 1966), p. 120. N6630756.

[60] Aviation Week, February 15, 1960, p. 31.

[61] V.S. Sokolovsky, quoted by Robert G. Smith, op.cit., p. 427.

[62] NASA Space Science and Applications, A Survey of Space Applications for the Benefits of All Mankind, (April, 1967), p. 14. NASA SP 142.

Early in the space program, it was anticipated that the Air Force would need space vehicles to intercept, inspect, and destroy hostile spacecraft.[63] As experience was gained with constraints placed on docking by expenditure of fuel, discussion of this possibility seems to have stopped. With future rendezvous techniques, and particularly if the shuttle is developed, this possibility may again become viable.[64]

MOL (Manned Orbiting Laboratory) was designed to test the desirability of adding a man to the surveillance system (although some observers contend that the primary objective was to find or create a task which could be used to justify a military space program). No public announcements were made as to the types of cameras and sensors which would be used or how these would improve on existing automatic systems or on those which might be flown in Workshop. There was however specultation in the trade press[65] and in the popular press:

> An even more useful spy satellite is still to come. The MOL...not only will carry the usual cameras and sensors but will have television cameras on board which can zoom in on installations for a close-up look. Other equipment will be able to pick up radar beams and all manner of communications.... The trained technicians on board will immediately evaluate the information and flash the most important to Earth and store the rest for later exploitation.[66]

MOL was delayed for at least two years beyond its original target date of 1969 because of several successive budget cuts. Before its

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[63] U.S. News and World Report 61, Sept. 26, 1966, p. 74.

[64] Lynn S. Diament, "Space Rendezvous," Space/Aeronautics, V. 52, 3, Aug. 1969, pp. 44-50.

[65] For example, "Manned Space Missions," Space/Aeronautics, V. 51, No. 1, January 1969, p. 50.

[66] U.S. News 63: September 9, 1968.

test flight, it had been rendered obsolete by the swift development of automated surveillance satellites, especially the Samos program. About 150 surveillance satellites had been put into orbit during the nine years of the space program[67] and it had become increasingly obvious that a manned program could find little to justify its cost, which would finally have been in the neighborhood of $5 billion. Some observers still believe that had MOL been completed on schedule its information would at that time have justified its cost[68] but with few exceptions they also agree that at the present time "automated devices can do most of the important orbital jobs and it is too expensive to build man into the system."[69]

The claim has been made, for example by Leonard Schwartz (Consultant to the Directorate for Scientific Affairs of OECD), that influential Johnson advisors pushed the MOL project because of the potential value of surveillance systems for purposes of arms control and inspection.[70] Schwartz has proposed either an internationally owned and operated space station or the transformation of the Arms Control and Disarmament Agency into a powerful operating agency with a space station for monitoring arms control agreements.[71] To many of those who presently object

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[67] Space Business Daily, Vol. 44, No. 32, June 16, 1969, p. 200.

[68] William Leavitt, "Apollo 11: Meaning Beyond the Moment," Air Force/Space Digest 52, No. 8, August 1969, pp. 52-55.

[69] Ibid.

[70] Leonard E. Schwartz, "Manned Orbiting Laboratory -- for War or Peace?" International Affairs 43: 51-64, January 1967.

[71] Ibid.

to such an extention of the space flight program, this would go far toward justifying the cost of development of space stations. However an automated system could presumably perform the same task. A possible, but not empirically demonstrated, benefit from U.S. space activities is increased national self-esteem and international prestige:

> Even now it is likely that a continued space effort... is indicated as part of our effort to communicate not only to our own people but to those in less developed countries that a free society is a prosperous society and that it would be advantageous for other nations to adopt a form of government which is able to invest a significant fraction of its gross national product in such public undertakings.[72]

The U.S.S.R. of course has also, possibly with less internal friction, been "able to invest a significant fraction of its gross national product" in space technology; and South Africa as well as Australia has taken the path of planned government-industry cooperation to attempt to compensate for relative lack of resources in developing research programs; yet there is no evidence of a strengthening of democratic sentiment or institutions in those countries.

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[72] James Fletcher, "The Space Program - A Social Enigma," Impact of Space Exploration of Society, p. 41.

IV. MEDICAL BENEFITS FROM SPACE

Much effort has gone into space medicine because of the unpredictability of human reactions to the extremes of gravity, temperature, and radiation in space. This has produced benefits to Earth medicine in a number of areas:

-- Medical instrumentation

-- Medical education

-- Hospital planning and public health services

-- Data collection and information systems

-- The study of environmental effects and stress

-- The study of physiological systems

An important benefit of the general space program has been the spin-offs of bioinstrumentation. Some instruments were developed directly for use in the space program, many of them for monitoring the reactions of astronauts in real or simulated flight. Others were adapted to medical uses. A list of such instruments, illustrative rather than comprehensive, will be found in Table III, (pp. 42-43).

NASA's Office of Technology Utilization has an active biomedical program which tries to do two things: to seek answers from aerospace technology and knowledge for specific medical questions, and to identify aerospace technology which may have potential medical value and make this known to doctors and medical researchers.

Early studies of the reactions of astronauts after space flight showed some effects: an increase in white blood cells, a decrease in red blood cells, a reduction in bone calcium, and circulatory difficulties.[73]

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[73] General Electric Co., op.cit., p. 3.

TABLE III

Instrument	Explanation of uses	Developed from	Stage (2)	Reference (3)
Vest electrocardiogram	Takes a number of electro-cardiograms simultaneously	Astronaut monitoring in flight	A	R1
Electrocardiograms by telephone	Long distance diagnosis and consultation	Aerospace industry spin-off	B	R2
Blood velocity meter	Can be placed on skin above blood vessel to be monitored	Astronaut monitoring in flight	B	R1
Intra-arterial catheter	Threaded through hypodermic needle, measures pressure in heart	Used in small flight models for wind tunnel tests	B	R1
Particle counter	Monitoring hospital "clean rooms"	Clean room fabrication of space instrumentation	B	R3
Orthopedic stretcher	Rescue and surgery		B	R3
Urinary valve	Urinary control for paraplegics	Instrument valves for space	B	R3
Computer enhancement of X-ray photographs	Precise X-ray information	Planetary exploration, unmanned	A	R4
Wheelless wheelchair	Allows patient to climb stairs	Vehicle for lunar surface	C	R4
Respirometer	Monitoring, assisting respira-tion	Astronaut monitoring in flight	A	R4
Neurological tremor measurement device	Diagnosis	Space instrumentation	B	R4
Titanium alloy	Artificial joint	Mechanical bearings	A	R5
Sight switch	Activating motorized wheelchair	Monitoring instruments	B	R5
Physiological Monitors	Intensive Care Units	Monitoring astronauts in flight	A	R5
Sponge Electrodes	Monitoring EEG of epileptics	Monitoring astronauts in flight	B	R6
Gold-iron Electrodes	Determining skull injury	(1)	(2)	R7

Radiation Probe	Control of radiation treatment	(1)	(2)	R7
Blood bank inventory	Control of resources	Computer technology	A	R2
Power sources	Artificial heart implant	fuel cell, on-board power	C	R8
Heart assist pump	Failing circulation	pump for life support systems	A	R8
Lazer surgery	Eye, cancer operations	Lazer technology	A	R8
Semi-automatic dialysis	Kidney failure	(1)	B	R8
Hosiptal information Service		Computer technology	B	R8
Air transportable Hosiptal, Pharmacy	Natural disasters, war	(1)	B	R8
Spray-on Electrodes	Monitoring during exercise	Astronaut monitoring in flight	A	R5

(1) Origin not given in reference cited.

(2) Stage of development unclear or unknown

- A - Already in use
- B - Under development
- C - In preliminary design or planning stage

(3) Key to references:

R1 - U.S. Congress, House, Authorizing Appropriations to NASA, FY 1969, Report to accompany HR 15856, Rept. No. 1181, 90th Congress, 2nd Sess., March 19, 1968, p. 375.

R2 - Aerospace Industries Association, "Aerospace Technology, Creating Social Progress," Washington,D.C. n.d.

R3 - NASA Office of Technology Utilization, "Summary Descriptive Information on a Random Selection of Transfer Examples," March 1969, mme.

R4 - NASA, "Medical Benefits from Space Research," mme., n.d.

R5 - United Nations Conference on the Exploration of and Peaceful Uses of Outer Space, "Space Science and Technology: Benefits to Developing Countries," Vienna: August, 1968.

R6 - NASA Office of Technology Utilization, "Indirect Benefits of Aerospace Research," mme., n.d.

R7 - Richard L. Lesher, Asst. Adm. for Technology Utilization, NASA, Statement before the Senate Committee on Aeronautical and Space Sciences, April 28, 1969, mme.

R8 - Stuart Bondurant, "The Impact of the Space Program on Medical Research and Practice," The Impact of Space Exploration on Society.

These effects were less intense on longer flights than on the earlier, shorter flights, which may mean that the body adjusts to the changed conditions. On the other hand, although these effects are not prohibitive so far, and man can perform successfully up to two weeks in space, the possibility remains that "man's powerful compensatory mechanisms tend to mask effects of a continuing stress until, after weeks and months, a whole system may abruptly collapse.[74] Research in the medical and biological aspects of space flight may produce valuable information about the effects of stress on human beings, directly applicable to Earth medicine, and about the effects of the circadian (day and night) rhythm as well.

Some physiological systems have been incompletely studied until now because some element of the control system has a very long time constant or responds very slowly to a given input, for example, the circulatory system, or the bone-calcium flux system. Because of the effect of gravity on these systems, they are now being studied intensively in preparation for long space flights.[75]

In the areas of environmental effects, stress, and physiological systems, further advances in medicine may proceed directly from development of space stations as the next step in long-duration flight. The Space Science Board said, in 1965: "The report of the working group on medicine and physiology concludes that before man can be safely included in missions of planetary duration, an orbiting research facility

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[74] Stuart Bondurant, op.cit., p. 3.

[75] Ibid.

for the study on long-term effects of space flight is essential.[76] Space stations could produce real contributions in the medical area.

In addition, there have been important spinoffs from space science. The United Nations Conference stressed the importance of the new application of systems approach to hospital planning and public health service planning.[77] Modern data collection and information retrieval services and computer technology, which has developed with great rapidity at least in part because of the push form the space program, is being increasingly applied to the administration and practice of medicine in such areas as hospital information service, computerized diagnosis, and disaster simulation.[78] Most of these applications are in a very early stage and cannot be fully evaluated as yet.

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[76] NASA Office of Space Science and Applications, Objectives and Goals, p. 65.

[77] United Nations, op.cit.

[78] Stuart Bondurant, op.cit., p. 196.

V. INDUSTRY BENEFITS FROM SPACE TECHNOLOGY

> I consider the space program as the cutting edge of our technological advancements... because there is no other national program that involves so many branches of technology and science.... If we want to keep our industry strong, our economy sound,... we cannot afford to allow this cutting edge to get blunted.
>
> \- Wernher von Braun[79]

Past and Present Benefits

Optimists hold out the promise that an active space program can act as "a substitute for war" in forcing the economy. The planning and the focusing of effort which occurs during an all-out war effort brings about technological advances and acceptance of new applications in a very short time period; for example, during World War II, radar, television, insecticides, and atomic energy were rapidly developed. Somewhat the same kind of forcing was brought about at the peak of the space program, when it involved the efforts of 20,000 contractors, 420,000 workers, and 200 universities and research groups.

Skeptics reply that non-space applications of space technology to date have amounted to little more that gadgetry, not sufficiently beneficial to justify the expenditure of resources on such a large scale while Earthly problems such as poverty, pollution, and population explosions are untouched. However, there is a time lag in the utilization of any new technology. Airplanes and automobiles did not achieve widespread commercial use for about two decades after their introduction.

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[79] U.S. Congress, House, Authorizing Appropriations to NASA FY 1969, Rept. No. 1181 to accompany HR 15856, 90th Cong., 2nd Sess., March 19, 1968, p. 921.

What has been called "the hurdle of user acceptance" requires a fairly long period of exploratory efforts directed at developing new applications before a technology is fully utilized.

A Department of Labor publication, entitled "Technological Trends in Major American Industries," identified nine areas of technological innovation which will have the greatest impact in the near future.[80] Using this categorization we can briefly mention some of the major impacts of the space program on industry to date, and consider whether any of these impacts will be greatly increased by the development of space stations. The nine trends are:

- -- Computerization, data processing
- -- Instrumentation, process control
- -- Increased mechanization
- -- Progress in communication
- -- Advanced metalworking operations
- -- Developments in energy and power
- -- Advancements in transportation
- -- New materials, products, and processes
- -- Managerial and related techniques

The multiplication of computers is said by some commentators to have an effect on society comparable to that of mass production of books in the 16th century and the mass production of the automobile in the first half on the 20th. Although computer technology began before the

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[80] U.S. Department of Labor Bulletin No. 1474, Technological Trends in Major American Industries, February 1966.

space program in the 40's, the demands of space flight have given a tremendous impetus to the developing technology.[81] Some experts have claimed that the advances in computer technology will save more money in the next decade for government and industry that the entire Apollo program cost.[82] At the present stage however, computer technology is not dependent on the space program for continued development because it has found such a wide range of applications. Nor does it appear likely that space stations will contribute heavily to computer technology as compared to other modes of space activity, although it may encourage further miniaturization.

Much instrumentation and improved process control techniques developed by NASA or by its contractors has been disseminated to other sectors of industry: Limitations of volume and weight in spacecraft led to accelerated development in solid-state physics, microminiaturization of electronic devices, printed circuits and molecular blocks for electronics components. In the same way, weight limitations and the temperature extremes of space led to radically different metal fabrication techniques, new alloys, and new plastics.[83]

Power sources and generation may benefit greatly from long duration space flight because of the need for on-board power sources; fuel cell technology has developed largely from the space program.

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[81]Robert C. Seamans, Jr., Sec. of Air Force, in the New York Times, July 17, 1969, 38C.

[82]James Clayton, "Apollo Lesson: Where There's a Will..." Washington Post, July 25, 1969, A26.

[83]NASA Office of Technology Utilization, Summary Descriptive Information of a Random Selection of Transfer Examples.

New materials and products from space technology to date include surface coatings, such as a nearly indestructable paint, ceramic insulation, sealants, lubricants, an electromagnetic hammer, pyrolytic graphite linings, thermionic emitter materials, and flat conductor cable.

Many observers believe that the most far-reaching effects of the space program are in "techniques for directing massed endeavors of scores of thousands of minds in a close-knit, mutually enhansive, combination of government, university, and private industry,"[84] such as the use of computer charts to spot trends and anticipate problems, "configuration management," a system of communication to ensure that engineering decisions made at one point do not have perturbing effects elsewhere in a production process, and the use of system analysis and operations research and the training of people in the use of these techniques.

Effects of the space program on industry have come from both the manned and unmanned flights. However because of the complex and critical demands of protecting men from the hostile environment of space and of launching a heavier payload, manned flight has probably produced more innovations in the way of structures, materials, and systems. The techniques of unmanned probes and satellites have already been worked out in their basic forms and future innovations may be mostly related to more sophisticated instrumentation on board.

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[84] Tom Alexander, "The Unexpected Payoff of Project Apollo," Fortune LXXX No. 1, July 1969, p. 114.

Space Stations and Industry

Early space stations will have as a primary function the investigation of industrial processes in a space environment. The object is to determine whether it is feasible to produce materials through processes which cannot be performed on Earth or which can be performed better in space because of factors such as vacuum, radiation, extremes of temperature, weightlessness, limitless space, and a sterile environment.[85]

Hans Wuenscher of NASA, discussing manufacturing in space, developed a typology of potential space manufacturing processes. Those which should work well in orbit include electron beam welding, exothermic tube brazing, high energy cutting, bonding, vapor deposition, and laser welding. Processes which work better than on Earth, because of the need for high refinement and small tolerances, might include manufacture of semiconductors and microelectronics and vapor deposition for solid state electronics. Some processes can work only in low or zero gravity.[86] Table IV indicates some of these.

Neither in this country nor in others have industrial leaders shown a great deal of interest in these promises as yet. Most comment has originated within NASA and the aerospace industry. This is, however, because the potential usefulness of such operations remains highly speculative until the development of space shuttles, which could reduce the cost of such activities by several orders of magnitude.

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[85] James R. Williams, "Space Manufacturing Modules," Paper to the 6th Space Congress, reprinted in Space Letter No. 341, April 1969, p. 1.

[86] NASA, Manufacturing Technology Unique to Zero Gravity Environment, George C. Marshall Space Flight Center, Nov. 1, 1969.

TABLE IV

	Process	Purpose - Example
Processes sensitive to buoyancy and thermal convection	Blending of materials of a different density in a plastic matrix	High altitude radiation shielding for aircraft; nuclear and thermal heterogeneous shielding
	Conversion of compacted powders and compounds into castings	Isotope fuel
	Composite casting	Comples high strength fittings, high strength brazing alloys, cermets
Processes controlled by molecular forces	Cohesion of surface tension casting	Ball bearings, optical components, large optical blanks, ellipsoidal and other bodies of revolution, hybrid computer components, high purity nuclear reactor castings
	Adhesion of layer casting	Multilayer isotopes
	Blow casting	Hollow spheres for ball bearings in large radar engines and tilt wings
	Controlled density casting	Structures with new optima in strength-to-weight ratio, temperature compatibility, and ductility, such as armor plate, bulk foam materials, varying density turbine blades, and sonar transducer materials

In other words, any process which can or might be performed in orbit will have to meet the cost-effectiveness test when it moves into the operational stage and becomes competitive with other methods. It is not always possible to predict this in advance. If space stations are to be developed it is reasonable that their utility for industrial purposes be assessed along with other potential applications, but this is not a demand which is being made by industry on NASA, the satisfaction of which would justify the expense of development. Rather, it is a highly speculative benefit the promise of which is being held out to justify a project which NASA regards as a necessary step in continuing manned flight.

VI. SOCIAL PROGRAMS AND SPACE

The space program is presently consuming much less than one percent of the gross national product, small compared to the share spent on defense (8.7 percent in 1969, 9.5 percent at the height of the Korean war)[87] but nevertheless a large allocation of resources. Since we are attempting to outline the benefits and detriments which might result from space stations, it is appropriate to consider the indirect or peripheral benefits and detriments which might result in terms of environmental quality, urban needs, education, and employment.

It is now frequently suggested that space technology be used to "solve" urban problems, or that the management techniques which put astronauts on the Moon be focused on a new national goal of abolishing poverty. Such prospects remain dubious. Julius Kane, a professor of mathematical ecology, has pointed out several reasons for this:[88]

-- Project Apollo had a clear, single-value objective, whereas in the domestic area the clashing of objectives and priorities makes a similar focusing of effort unlikely;

-- The space effort could gauge its progess precisely and unambiguously whereas quantitative indicators of human well-being are without a "clean" error signal that can be used for identification of mistaken directions;

-- Competing federal agencies have incompatible goals;

-- Federal agencies are discipline oriented rather than task oriented;

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[87] Statement by Rep. Edward I. Koch in introducing an amendment to NASA authorization bill for FY 1970. News release, June 10, 1969.

[88] In a letter to the Editors of Fortune, September 1969, p. 131.

-- Government responsibilities are fragmented along lines of political jurisdictions;

-- Funds are committed and therefore plans can be made for only one year at a time;

-- Political issues, unlike engineering problems, require education and persuasion of the public.

To these difficulties must be added the possibilities that some goals are inherently incompatible, that some problems may be unsolvable, and that some outcomes may be unpredictable.

Environmental Quality

Just as it is not clear that space-derived technology can alleviate human, urban, and environmental problems, it is unlikely that it will aggravate those problems. The possibility of back-contamination of Earth from the contact of space flight and extraterrestrial life is now considered extremely unlikely. It is possible that abandonment of hardware and organic byproducts in space could have detrimental effects not as yet recognized.

One of the more extreme proposals for the use of outer space is the suggestion of Freeman Dyson, of Princeton's Institute for Advanced Studies, that outer space and the solar wind be considered as a "magnificent garbage disposal system for the use of man."

> If humanity were to be forever confined to Earth, the problem of pollution could hardly be solved without an enforced economic stagnation... the sum total of industrial processes threatens to hear the Earth's atmosphere to an intolerable extent within a century or two at present rates of economic growth... (It will) probably become socially desirable... to move many of the messier industries into space. The solar wind is a magnificent garbage disposal system....[89]

[89] Freeman Dyson, "Human Consequences of the Exploration of Space," Bulletin of Atomic Scientists XXV, No. 7, p. 13.

More conservatively, satellites can be used to warn of extreme air pollution conditions. On-board waste disposal and reclamation devices for spacecraft may eventually be adapted for residential use. Creation of artificial atmospheres for space stations might provide technology for creating an atmosphere for cities. In all of these potential applications, further development will probably lag for lack of marketability, a need which does not limit space programs.

Housing

Many space-derived innovations in materials, structures, tools, and construction techniques have potential application in housing construction. The technology of life-support systems, waste disposal and reclamation, and rocket fabrication might be applied to the housing of the future, since housing is basically the creation of a closed environment. Thus space station experiments in habitability, living space needs, and environmental control might have applicability in housing construction if legal constraints such as building codes can be overcome.

Because of the existing constraints few space-derived applications have so far been adoped by the housing industry.

Transportation

Research and development of SST, VSTOL, and conventional aircraft is carried on under NASA's original authority and the aerospace industry has a full program of research in air transportation. However the need is for greater use of the same capabilities in urban transportation.[90]

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[90] Tempo Division, op.cit.

The major needs are for systems analysis of the entire transportation system, computerization, new power sources, and new modes of flexible but swift land transportation.

There could be spin-offs from a space shuttle, when one is developed.[91] But whether hypersonic or orbital flight will ever be cost competitive with conventional jet aircraft is a big question. (It has been calculated that the cost of running commercial jet service from New York to Los Angeles would be comparable to the cost of space flights if the same ground rules were observed, namely, that there was no more than one flight a month, that the airplane were thrown away after each flight, and that the costs of the two airports were covered by the freight charges.)[92]

The Contribution of the Space Program to Employment and Economic Stimulation

In 1958 NASA had 8,000 employees;[93] this rose to 35,000 at the peak in 1966 and declined slightly in 1969,[94] and more rapidly last year. The aerospace industry is the largest manufacturing industry in the

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[91] Sidney Hyman, "Man on the Moon - the Columbian Dilemma," Bulletin of Atomic Scientists XXV No. 7, September 1969, p. 18.

[92] Theodore Taylor, "Propulsion of Space Vehicles," quoted extensively in Freeman Dyson, op.cit.

[93] Robert L. Rosholt, op.cit.

[94] U.S. Congress, Senate, NASA Authorizations for FY 1969, Hearings before the Committee on Aeronautics and Space Sciences, 90th Cong., 2nd Sess., Pt. I, pp. 70-71.

country in numbers employed.[95] The number employed in NASA projects was about 410,000 at the peak. Scientists and engineers make up 16 percent of aerospace employees (higher on space projects)[96] This is about 1/5 of all U.S. scientists and engineers, and tends to make the space industry, like the defense industry, subject to "sectoral depresion." This concept, which is not accepted by all economists,[97] means that expenditure for high technology projects tends to be self-generating because the liklihood is high that when concentrations of scientific and engineering talent are assembled they will tend to generate new concepts leading to further advances in technology and increased industrial activity. A cut-back in space and defense industries, according to this argument, has a disproportionately adverse effect on the economy in the long run. It has also been argued that space workers are trained for special skills not completely transferable to other segments of the industry and therefore are subject to a particularly persistent form of unemployment, especially the scientists and engineers. Thus the maintenance of a space program, but not necessarily of space station projects, could be one support for a sagging economy.

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[95] Aerospace Industries Association, Aerospace Facts and Figures, 1969 Report, Compiled from Bureau of Labor Statistics data.

[96] Ibid.

[97] See controversy in the Washington Post, "Severe Jolt to the Economy Predicted if Drive to Cut Arms Budget Succeeds," by Frank Mankiewicz and Tom Braden, A17, August 12, 1969, and "Arms and the Economy," by Henry D. Wyner, Senior Economist with USACDA, A24, August 22, 1969.

The Space Program and Miscellaneous Urban Problems

In many other social problem areas such as the development of information systems, urban planning, and education, to name a few, space technology may well make indirect contributions, but it is unlikely that much impact will come directly from the development of space stations. However it should be emphasized again that NASA's continued capability as a research agency may depend on providing it with new post-Apollo objectives.

One of the greatest benefits to education from space technology is the development of synchronous equatorial satellites which will permit direct reception of educational television by even small village schools.[98] Educational television allows one teacher to serve three to four times as many pupils as by conventional methods.

It appears however that space stations will make no unique contribution in the field of education.

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[98] United Nations, op.cit.

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CONCLUSIONS

According to news stories, a Special Science and Technology Panel chaired by Dr. Lewis N. Branscombe of the National Bureau of Standards has reported to the President that the manned space flight program has not adequately assessed either the dangers to men in long-duration space flight, or the contributions which such manned systems would make to society. This report has not yet been made public, but both of these points are quite valid and must be kept in mind in assessing the potential social impacts of an operational system of space stations. The following conclusions are offered therefore as a basis for further discussion of the social desirability of allocating resources to the development of space station systems and of their proper place in the hierarchy of social values.

Development of a system of space stations-long-duration manned facilities operating in Earth-orbit-can be justified with assurance if-and only if-either of two objectives is accepted: (a) maintenance of a manned space flight program with the deliberate purpose of maintaining our options for future space activities, (b) manned exploration of the planets, for which space stations are desirable as training facilities and as logistical facilities.

It may be argued that manned planetary exploration is unnecessary since instrumented probes can probably be made to answer all the questions we can now ask about planets at a relatively small part of the costs of manned flight. However, since History indicates that explorations which are within man's capability will be made by some nation at some time in the hope of national advantages, political pressures and national pride may eventually dictate the acceptance of this goal.

If a system of space stations is developed, it will bring about substantial benefits in the areas of science, practical applications, medical knowledge, and industrial spin-offs. It does not appear that these benefits are sufficient to justify by themselves the development of space stations. Therefore space stations must at the present be placed rather low in the hierarchy of social goals.

Manned space flight has been an engineering and technological effort to which scientific (experimental) considerations were secondary. While scientific knowledge has been expanded by manned space flights and would continue to benefit from experiments performed in connection with space station projects, this benefit is probably much smaller than that which would be derived from comparable expenditures in unmanned space programs and in other forms of scientific experimentation.

Benefits to astronomy and physics have come chiefly from unmanned systems, and there are some positive disadvantages from the addition of man to the instrumented systems, while potential benefits from space stations are speculative and appear to be disproportionately expensive. Geodesy is unlikely to benefit from space station systems. On the other hand, bioscience appears to be the discipline most likely to benefit greatly from further development in this direction.

There is little convincing evidence that Earth resource surveys, oceanography, meteorology, communications, navigation, or traffic control would benefit from a human presence sufficiently to justify the cost and disadvantages. However there would be some benefits in those applications where rapid selection, analysis, and transmittal of information is crucial.

The chief military benefit from space is in surveillance, which can be performed more economically and perhaps more efficiently by automated systems. This is also true in regard to arms control inspection. Industrial benefits from space stations are especially dependent on the development of very cheap space transportation. While the benefits could eventually be large, they do not appear to be necessary in the sense of meeting urgent needs.

Medical knowledge has been increased by the manned space flight programs and some additional benefits might be derived from space stations. However more direct medical benefits might accrue from allocation more resources directly to medical research on Earth.

Space stations, apart from other space systems, are not likely to make unique contributions to the solution of social problems. Environmental quality could benefit from space technology such as life-support systems. However there may be as yet unrecognized detrimental impacts in the form of contamination and pollution from orbiting factories, hospitals, and transportation systems, both on the Earth environment (launch, exhausts, fuel production, etc.) and on future uses of space.

There are potential benefits to housing from space station technology but their utilization will require much revision of existing codes and practices. There may be spin-offs from the space shuttle program to Earth Transportation, but it is fairly unlikely that they will be in the area of most pressing need, urban transportation. Information systems, urban planning and development, and education have benefited in varying degrees from space technology but are unlikely to reap significant benefits from space stations projects in particular.

Finally, while the economy benefits from the space program, as from other large government expenditures, it appears unlikely that reductions in the space program will in themselves have serious economic effects.

For all of these reasons, while space station systems appear to be reasonable as one of many long-range national goals, it also appears they should be assigned a low priority in view of far more urgent social needs. There are two limitations on this conclusion:

(a) Under our free enterprise system, it is only public expenditures which are popularly perceived as competing, while enormous aggregate expenditures on frivolities and luxury items go unnoticed in this regard although their detrimental impacts may be very large (tobacco, for instance) and their beneficial impacts negligible. It is quite likely that the total amount of resources spent for public purpose could be increased if the American people decided to pursue their national goals more decisively.

(b) There is a lower level beyond which reduction of the space effort will make it impossible to hold together a viable scientific-industrial team capable of keeping our options for future uses of space. In terms of this level of effort, space stations may be a more rational goal than further manned planetary exploration.

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